Remarks

General

The Examiner's allowance of Claims 28-37 is greatly appreciated. The timely issuance of Wright 6,657,847 and Haghgooie 6,681,728 during consideration of Applicants' invention presents a further opportunity to distinguish the present invention from the current state of the art. Applicants herewith amend the specification to incorporate discussion of these new references cited by the Office Action. Claims 1-27 are thereby revised to further emphasize their distinction over the prior art and the truly novel benefits they bring to the field.

Review of the References cited in the Office Action

Reference A — Wright, et. al. (U.S. 6,657,847)

Wright '847 proposes a method for determining the position of a moving solenoid armature based upon continuous dynamic measurement of inductance during its entire time of flight — an extension of an earlier effort, since issued as Wright, et. al. (U.S. 6,285,151) and cited both by Applicants and by Wright '847 as in need of improvement. In the words of Wright '847:

> "Generally, PID (proportional, integral, derivative) control systems can only perfectly compensate a linear system with state variables that are not interactive. Electromagnetic actuators are, however, highly non-linear (and) the state variables are highly interactive."

In Applicants' words:

> "These methods provide empirical formulas for specific points of course correction (and) provide some measure of control, but less than is needed for a versatile, quiet-running and log-lasting system."

Reference B — Haghgooie, et. al. (U.S. 6,681,728) (properly Peterson, et. al.)

Haghgooie '728 discloses a method for controlling a solenoid by contiuously and directly measuring its position using a displacement transducer. As with Wright '847, Haghgooie '728 views the control problem from the standpoint of being in the right state at the right time and teaches a method of continuously monitoring velocity, position and current together and trying to adjust voltage each time an error is observed.

Curiously not cited by Wright '847 or Haghgooie '728, but highly relevant, is Bergstrom (U.S. 6,249,418) granted on June 19, 2001: "System for Control of an Electromagnetic Actuator." Bergstrom '418 teaches important details that serve as background to Applicants' invention and are also helpful in understanding the difficulties faced by Wright, Haghgooie and others in the prior art.

Reference C — Ito, Nobuyasu (U.S. 6,634,248)

Ito '248 teaches a switch interlock system which allows shifting of a vehicle's transmission from forward to reverse only appropriate conditions. The on/off state of the switches and associated latching relays is used to operate conventional uncontrolled solenoids.

Reference D — Seale, et. al. (U.S. 6,208,497)

Seale '497 discloses a system for servo control of solenoids and other mathematically non-linear electromagnetic actuators. Within Seale '497 lie the seeds of Applicants' present invention.

Reference E — Osborne, et. al. (U.S. 6,366,199)

Osborne '199 teaches a system for collecting and storing data from a variety of sensors to gather information relevant to automobile warranty and risk assessment.

The Rejection of Claim 1 under 35 USC §103(a) is overcome

The Office Action has rejected independent Claim 1 over Wright '847 in view of Ito '248. Claim 1 has been rewritten as new Claim 38 to more clearly define patentably over these references and any combination thereof.

While Wright '847 clearly discusses a control system for solenoids, there are major distinctions between Wright '847 and Applicants' approach to the methods involved. Wright '847 describes a method of continuously reading the position, the velocity and the supply current of a solenoid in motion, reacting with corrective measures after each reading, and then iteratively repeating the process.

Applicants' method compares the present state of a solenoid, upon demand, to a predetermined set of trajectories in an hypothetical state space, and then provides early and proactive changes to the driving conditions which smoothly coerce the flight trajectory of the solenoid to a successful soft landing. Using this approach demands preexisting trajectory information, and it avoids abrupt changes in flux which in the face of physics cannot be actually made. Applicant's approach is not only simpler but also more reliable and more robust.

Applicants respectfully request reconsideration of this rejection, as now applicable to Claim 38, for the following reasons:

1. Applicants' invention produces new, unexpected and disproportionately superior results when compared to any prior art, by using familiar information in a different way. This new way is unsuggested and unrecognized in the prior art and produces unusual improvements in motion which are recognized, even in the prior art, as critical to engine valve life and thus to the early adoption of this technology for internal-combustion engines. Such adoption is known to be capable of reducing both fuel consumption and global environmental damage.

Wright '847 (and others) teaches a method using as frequent as possible readings of the position, the velocity and the supply current for a solenoid armature in motion, and teaches immediate corrective reactions based upon any difference between these immediate readings and the values of contemporaneously generated "running set-points" corresponding exactly in time with the moment of the readings. If the difference is small, the correction is small, but if the difference is large, for example because a valve momentarily "sticks" along its path through the valve guide, or if any single measurement is in error, then the corrective measure can be large.

The aim in the prior art is to closely scrutinize the progress of each armature stroke to determine if it is where it should be, when it should be. Over the years, small incremental improvements in this process have led to higher and higher expectations of solenoid control. But one problem continuously faced has been the physical fact that inductance within the magnetic structure of any solenoid always resists any change in current, and the more rapid and higher in magnitude that change, the more the solenoid resists it. Exceedingly high voltages may be needed in an attempt to drive such instantaneous currents, as may be appreciated by the fact that standard ignition coils generate their sparkplug voltages in exactly this way.

Applicants have recognized an entirely new way to apply controls to a moving solenoid, using prior knowledge of the many ways the solenoid system may behave in terms of its instantaneous velocity or kinetic energy, its instantaneous location or potential energy with respect to its spring system, and the magnetic flux linkage acting as a general force adding or subtracting energy to the solenoid over time. Applicants make no attempts at all to instantaneously change the state of the solenoid, as in the prior art, but rather they use a proactive change in magnetic flux linkage over a period of predicted time, to steer the solenoid toward and gradually onto a trajectory that will end in a successful landing and latching.

Since the dawn of the invention of internal combustion engines, mechanical mechanisms have been used to move the valves open and closed, and until recently these mechanisms have created a fixed

relationship between the crankshaft position and the valve position. It has long been realized that this is not an optimal situation, and special camshafts for racing and for high-torque applications such as farm tractors have been commonplace. Recently, variable valve timing mechanisms have become common, where the entire camshaft itself is moved with regard to the crankshaft, or where linkages between the camshaft and the valve are re-structured to change the valve motion. None of these are yet the optimal solution.

Independent control of each valve, as may be effected with solenoid actuation, is a much larger step in the right direction. With it, substantial gains can be made in fuel economy and exhaust emissions. This is a critical issue today.

2. The failure of the prior art to arrive at the results Applicants obtain shows clearly that Applicants' solution was not obvious at the time of invention.

Although many in the prior art, and including some of the references cited, have labored hard and long to reach the goal of smooth, quiet landing with latching control, none have reached the goal. Applicants have done so, as is evidenced by Figure 1 showing the actual performance of a valve/solenoid system under Applicants' control. The mathematics and physics underlying a solenoid system are non-trivial, as attested in the all the prior art and current research papers.

3. The fact that companies such as Ford (Haghgooie '728) and Siemens (Wright '847), who have major global stakes in the field of internal combustion engines, are dedicating resources to the resolution of this problem indicates clearly that even small improvements in this crowded art are significant. Applicants' solution is not small.

As mentioned above, this problem is important. Major worldwide companies, from manufacturers of engines such as Ford and others to manufacturers of engine management systems such as Siemens are spending appreciable time and money on the problem. The patents and papers teaching of progress in this field attest that small improvements are appreciated, that larger improvements are desired, and that Applicants' solution will be welcomed.

4. Using sensorless control in the Applicants' manner reduces the complexity and increases the robustness of prior art systems such as Haghgooie '728 which teach the use of external sensor means such as a linear variable differential transformer (LVDT), which not only introduce their own nuances to measured signals, but also have their own vulnerabilities in an under-the-hood

application.

Over the more than 110 years that poppet valves have been the standard for controlling intake and exhaust gases, and as reliable as they have become, they still are subject to wear and premature failures. In effecting a replacement for the current designs, nothing must cause a worsening of reliability or unavoidable increases in cost. Applicants have been working on sensorless control of magnetic actuators for just this reason, and they make every effort to not add levels of complexity or unnecessary mechanisms or sensors that might introduce their own costs or frustrations.

5. Nothing in the prior art suggests or has ever suggested that said prior art be modified, as it must be, to meet Claim 1 — Office Action statements notwithstanding.

Both the control methods and the mathematics which are used in the prior art, and which work hand-in-hand, are drawn from classical approaches. Both these would require restructuring, independently and together, in order to implement Applicants invention.

6. The prior art references are inoperative to the degree that they are incapable of producing the Applicants' beneficial results. Furthermore, while they each may constitute an improvement over their own prior art (which point is arguable), the mathematics and physics underlying their approach does not entirely support the results that would obtain.

As mentioned above, Wright '847 teaches a control method which is immediately and highly sensitive to any discrepancy between where the solenoid is and where it is expected to be. As pointed out clearly by others as well, a solenoid has two broadly different (and overlapping) regions of operation: the far-away region, where (in Katherine Peterson's words) "control authority" is weak, and close-in where the magnetic field is so non-linear and steeply sloped that control is almost out of control.

Ito '248 teaches a method of controlling a vehicle shifting apparatus using a switching and latching relay network to uncontrollably (in the current sense) turn on and off solenoid actuators. Nothing in the teachings or apparatus of Ito '248 could operate as solenoid control in the context of Applicants' invention.

7. The references are vague in critical areas, which predicates that their teachings must be considered narrowly and not construed broadly.

As mentioned above, the methods and mathematics disclosed by Wright '847 are not wholly consistent with the results they obtain. Furthermore, there are within the Specification a number of critical errors which may be errors in printing or errors in logic. Critical discussion of Figure 9, which appears to show actual solenoid motion, is vacant from the Specification, and reference is made in several places to Figure 15, which does not exist at all. As such, the teachings of Wright '847 must be read, construed and applied very carefully and very narrowly.

8. The fact that those skilled in the art, and obviously working on the problem at hand, have not implemented the invention, despite its great advantages, indicates that it is not obvious.

As mentioned earlier, independent control of each valve is a critical issue in the field of fuel economy and exhaust emissions. That no one has implemented Applicants' invention speaks to its unobviousness.

9. Ito '248 does not teach what the Office Action relies upon it as supposedly teaching.

Ito '248 teaches a system, indeed using solenoids but not controlling solenoids' actual paths of motion, for the control of a vehicle transmission to prevent accidental engagement. The control system taught by Ito '248 has no bearing on the control of solenoid motion as considered by Wright '847 or Applicants.

10. The Office Action has made a strained interpretation of the references that could be made only with hindsight.

Nothing in either Wright '847 or Ito '248 talks of state-space control. Applicants have clearly supported in the Specification what is meant by the terminology of Claim 1, which is entirely different from many of such similar terms as used by Wright and by Ito. Nowhere is there the inference that Wright '847 discloses means for obtaining parameters indicating the position in state space of a controlled solenoid, nor a path memory means indicative of paths in a state space. Nowhere in Ito '248 is there the suggestion of drive control means setting an output signal in accordance with path memory means, nor indeed of any path memory means at all. Such is simply not germane to the solution of Ito '248.

11. Applicants teach a new principle of operation; they have not followed the lead of the prior art.

Nowhere in the prior art is the suggestion that state-space control be used in the control of a solenoid, nor the expectation that such could be implemented, nor the prediction that if it could, the results would be the solution to this long-standing puzzle. Applicants alone have recognized this approach.

12. Applicants solve a wholly different problem from Ito '248, which fact is made clear in the Claims.

As mentioned above, Ito '248 confronts the problem of a vehicular transmission inadvertently being shifted in to motion or particularly from forward to reverse motion while underway. Ito '248 uses an electrical control circuit to sense the current operating condition of the vehicle and therewith to use the control circuit to prevent inadvertent on/off switching of the solenoids which actuate the transmission. Other than "fully off" and "fully on," Ito '248 makes no attempt to control the solenoid.

Applicant (and Wright '847) face the entirely different, and more subtle, problem of controlling the details of motion of the solenoid along its path from "fully-off" to "fully-on," such that it lands softly and latches in position at each end of its stroke.

13. The Office Action presents no convincing line of reasoning as to why the claimed subject matter, as a whole and including differences over the prior art, would have been obvious.

In the Office Action are numerous statements regarding the obviousness of Claim 1. Few, however, present a clear argument in support of themselves, and none show how Claim 1 would have been obvious.

14. The prior art contains no suggestion that the references be combined in the manner stated or to reach the same results.

Wright '847 makes no suggestion that the control apparatus of Ito '248 for vehicular transmissions could ever in any way be combined with the invention of Wright '847, in any manner; Ito '248 makes no suggestion that the control system of Wright '847 could ever in any way be combined with the invention of Ito '248 in any manner. Neither suggests that any benefit would accrue therefrom.

15. The references are individually complete in themselves. There would be no reason to change their teachings or to add new material.

Wright '847 teaches a method of using inductance to determine the position of a solenoid, and claims that said method is successful. Nowhere does Wright '847 suggest a reason for incorporating a shift control apparatus or method to improve the use of induction in determining said position.

Ito '248 teaches a shift control method and apparatus for operating an vehicular transmission. There is no hint in Ito '248 that such apparatus or such method would benefit in any way by the Wright '847 method of measuring the position of a solenoid. Indeed, Ito '248 nowhere makes mention of the position of any solenoid, nor of the relevance of any solenoid's position.

16. Ito '248 is from an entirely different field than that of the invention, and thus is nonanalogous art.

Ito '248 deals with the field of vehicular control and safety. Applicants in no way consider the control or safety of a vehicle, but deal instead with the control of a solenoid or engine valve such that it lands smoothly and latches in position.

17. Even if combined as suggested in the Office Action, the references would not meet the Claim.

As stated above, Ito '248 teaches an apparatus and method using solenoids but not controlling solenoids' paths of motion. Wright '847 teaches a method of using inductance to determine the position of a solenoid. Neither speaks of state-space control, of paths in a state space nor of a path memory means. When combined is any manner, such combination would never provide a path memory means, paths in state space or control by using such state space.

18. The results achieved by the invention are greater than would be expected from the respective results of the references, individually or in combination.

Applicants' results, as manifest in Figure 1 as well as in the Specification, are clearly superior to those of Wright '847 in effecting a low-impact landing with latching. As ito '248 teaches uncontrolled solenoid motion, both Applicants and Wright '847 are manifestly superior to the results in Ito '248.

19. The combination of Wright '847 and Ito '248 would require a series of separate, awkward combinative steps that are too involved to be considered obvious.

Ito '248 uses a single wire connecting to a solenoid, the return path being through electrical ground. This permits solenoid 5 and 7 to be, in Ito's words, "energized" or "deenergized" by either passing

electrical current through control relays 6 or 8, or not. No additional wires, components or circuitry are needed.

To combine Ito '248 with Wright '847 would require, first, an isolated return circuit for individually measuring the electrical current passing through solenoids 5 and 7 separately. In addition would be required a controlled current source and voltage sense leads, and a digital signal processor. The net result would be a much more expensive and failure-prone device which could only reduce the solenoids' effectiveness by slowing them down from their normal fully-energized speed which is in any case preferred for actuating a transmission.

Further regarding Claim 1, now rewritten as new Claim 38, Wright '847 does not teach a memory means for storing and retrieving predetermined trajectory information, nor does it teach information describing a multiplicity of trajectories within a state space, such trajectories corresponding to a multiplicity of operating systems. Wright '847 does not teach a means for electively determining the present state of a solenoid, but rather uses an iterative, continuous series of measurements. Wright '847 does not teach means for comparing the present state with predetermined trajectory information, nor a drive control means for setting an output signal in accordance with a distance in state space whereby the dynamically changing state of a solenoid actuator is caused to approach a trajectory among a multiplicity of trajectories.

Ito '248 teaches at column 1, lines 27-29, a signal from a vehicular speed sensor which is supplied to a control unit that energizes two relays. It nowhere teaches or envisions drive control means for setting an output signal in accordance with a distance in state space, or with an error detection means or by comparison to a memory means.

The Rejection of Claim 2 under 35 USC §103(a) is overcome

Claim 2, re-written as new Claim 39, is dependent upon new and allowable Claim 38. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 3 under 35 USC §103(a) is overcome

Claim 3, re-written as new Claim 40, is dependent upon new and allowable Claim 38. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 4 under 35 USC §103(a) is overcome

Claim 4, re-written as new Claim 41, is dependent upon new and allowable Claim 40. Applicants

respectfully request reconsideration of this rejection.

The Rejection of Claim 5 under 35 USC §103(a) is overcome

Claim 5, re-written as new Claim 42, is dependent upon new and allowable Claim 38. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 6 under 35 USC §103(a) is overcome

Claim 6, re-written as new Claim 43, is dependent upon new and allowable Claim 38. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 7 under 35 USC §103(a) is overcome

Claim 7, re-written as new Claim 44, is dependent upon new and allowable Claim 38. Wright '847 teaches (see column 7, line 25) a flux (Figure 5, element 66) and not a flux linkage. As is clear in Applicants' specification, using flux linkage rather than flux itself produces an advantage. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 8 under 35 USC §103(a) is overcome

Claim 8, re-written as new Claim 45, is dependent upon new and allowable Claim 44. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 9 under 35 USC §103(a) is overcome

Claim 9, re-written as new Claim 46, is dependent upon new and allowable Claim 44. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 10 under 35 USC §103(a) is overcome

Claim 10, re-written as new Claim 47, is dependent upon new and allowable Claim 44. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 11 under 35 USC §103(a) is overcome

Claim 11, re-written as new Claim 48, is dependent upon new and allowable Claim 47. Wright '847 teaches at column 6, lines 1-17 an equation for voltage, such equation not involved with position at different times, nor with a measure of velocity as asserted in the rejection of Claim 11. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 12 under 35 USC §103(a) is overcome, for the following reasons

Claim 12, re-written as new Claim 49, is dependent upon new and allowable Claim 38. Applicants request reconsideration of this rejection, as now applicable to Claim 38, for the following reasons:

1. Osborne '199 discloses at column 2, lines 21-52, a processor for statistical data relating to automobile warranties. Osborne '199 does not teach what the Office Action relies upon it as supposedly teaching. it does not teach nor envision trajectories of a solenoid, nor the control thereof. The method and apparatus taught by Osborne '199 has no bearing on the control of solenoid motion as considered by Wright '847 or Applicants.

2. Osborne '199 is from an entirely different field than that of the invention, and thereby is nonanalogous art. Osborne '199 deals with the field of vehicular warranty data. Applicants in no way consider the warranty history of a vehicle, but deal instead with the control of a solenoid or engine valve such that it lands smoothly and latches in position.

3. The Office Action has made a strained interpretation of the references that could be made only with hindsight. Nothing in either Wright '847 or Osborne '199 talks of state-space control. Applicants have clearly supported in the Specification what is meant by the terminology of Claim 12, now Claim 49, which is entirely different from many of such similar terms as used by Wright '847 and by Osborne '199. Nowhere in Osborne '199 is there the suggestion of drive control means setting an output signal in accordance with path memory means, nor indeed of any path memory means at all. Such is simply not germane to the solution of Ito '248.

4. Applicants teach a new principle of operation; they have not followed the lead of the prior art.

Nowhere in the prior art is the suggestion that state-space control be used in the control of a solenoid, nor the expectation that such could be implemented, nor the prediction that if it could, the results would be the solution to this long-standing puzzle. Applicants alone have recognized this approach.

5. Applicants solve a wholly different problem from Osborne '199, which fact is made clear in the Claims.

As mentioned above, Osborne '199 confronts the problem of recording automotive warranty data for statistical analysis. Osborne '199 uses an electrical control circuit to record sensor data for subsequent reading by an off-vehicle data interface.

Applicant (and Wright '847) face the entirely different problem of controlling the details of motion of a solenoid along its path such that it lands softly and latches in position at each end of its stroke.

6. The Office Action presents no convincing line of reasoning as to why the claimed subject matter, as a whole and including differences over the prior art, would have been obvious.

In the Office Action are numerous statements regarding the obviousness of Claim 12. Few, however, present a clear argument in support of themselves, and none show how Claim 12 would have been obvious.

7. The prior art contains no suggestion that the references be combined in the manner stated or to reach the same results.

Wright '847 makes no suggestion that the apparatus or methods of Osborne '199 could ever in any way be combined with the invention of Wright '847, in any manner; Osborne '199 makes no suggestion that the control system of Wright '847 could ever in any way be combined with the invention of Osborne '199 in any manner. Neither suggests that any benefit would accrue therefrom.

8. The references are individually complete in themselves. There would be no reason to change their teachings or to add new material.

Wright '847 teaches a method of using inductance to determine the position of a solenoid, and claims that said method is successful. Nowhere does Wright '847 suggest a reason for incorporating a warranty data recorder or method to improve the use of induction in determining said position.

Osborne '199 teaches a method and apparatus for measuring and accumulating warranty data. There is no hint in Osborne '199 that such apparatus or such method would benefit in any way from the Wright '847 method of measuring the position of a solenoid. Indeed, Osborne '199 nowhere makes no mention of the position of any solenoid, nor of the relevance of any solenoid's position.

9. Even if combined as suggested in the Office Action, the references would not meet the Claim.

As stated above, Osborne '199 teaches an apparatus and method for recording warranty data. Wright '847 teaches a method of using inductance to determine the position of a solenoid. Neither speaks of state-space control, of paths or trajectories in a state space nor of a path or trajectory memory

means. When combined in any manner, such combination would never provide a path or trajectory memory means, paths or trajectories in state space or control by using such state space.

10. The results achieved by the invention are greater than would be expected from the respective results of the references, individually or in combination.

Applicants' results, as manifest in Exhibit 1 as well as in the Specification, are clearly superior to those of Wright '847 in effecting a low-impact landing with latching. Osborne '199 teaches and contributes nothing which would improve upon Wright '847 or upon Applicants' invention.

The Rejection of Claim 13 under 35 USC §103(a) is overcome

Claim 13, re-written as new Claim 50, is dependent upon new and allowable Claim 49. Wright '847 at Figure 3B, bottom two blocks, teach a method of iteratively reducing a proportional error in a single time-dependent path, and not the modification of predetermined trajectory information in a state space. as a result of a drift error among trajectories. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 14 under 35 USC §103(a) is overcome

Claim 14, re-written as new Claim 51, is dependent upon new and allowable Claim 49. Osborne '199 at column 3, lines 7-19, teaches using a database with vehicle operating data to obtain vehicle warranty statistical data by deriving a mathematical model, which may include the step of comparing the model to empirical data. Osborne '199 does not teach or suggest retrieving a multiplicity of numbered trajectories which better match predictive perturbations that are distinct from operating conditions or are descriptive of present mechanical energy arising from past events. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 15 under 35 USC §103(a) is overcome

The Office Action has rejected independent Claim 15 over Haghgooie '728 in view of Ito '248. Claim 15 has been rewritten as new Claim 52 to more clearly define patentably over these references and any combination thereof. Applicants respectfully request reconsideration of this rejection.

While Haghgooie '728 clearly discusses a control system for solenoids, there are major distinctions between Haghgooie '728 and Applicants' approach to the methods involved. Haghgooie '728 describes a method of continuously reading the position, the velocity and the supply current of a solenoid in motion (see equation at column 4, line 25), reacting with corrective measures after each

reading, and then iteratively repeating the process.

Applicants' method compares the present state of a solenoid, upon demand, to a predetermined set of trajectories in an hypothetical state space, and then provides early and proactive changes to the driving conditions which smoothly coerce the flight trajectory of the solenoid to a successful soft landing. Using this approach demands preexisting trajectory information, and it avoids abrupt changes in flux which in the face of physics cannot be actually made. Applicant's approach is not only simpler but also more reliable and more robust.

Applicants respectfully request reconsideration of this rejection, as now applicable to Claim 38, for the following reasons:

1. Applicants' invention produces new, unexpected and disproportionately superior results when compared to any prior art, by using familiar information in a different way. This new way is unsuggested and unrecognized in the prior art and produces unusual improvements in motion which are recognized, even in the prior art, as critical to engine valve life and thus to the early adoption of this technology for internal-combustion engines. Such adoption is known to be capable of reducing both fuel consumption and global environmental damage.

Haghgooie '728 (and others) teaches a method using as frequent as possible readings of the position, the velocity and the supply current for a solenoid armature in motion, and teaches immediate corrective reactions based upon any difference between these immediate readings and the values of "running set-points" corresponding exactly in time with the moment of the readings. If the difference is small, the correction is small, but if the difference is large, for example because a valve momentarily "sticks" along its path through the valve guide, or if any single measurement is in error, then the corrective measure can be large.

The aim in the prior art is to closely scrutinize the progress of each armature stroke to determine if it is where it should be, when it should be. Over the years, small incremental improvements in this process have led to higher and higher expectations of solenoid control. But one problem continuously faced has been the physical fact that inductance within the magnetic structure of any solenoid always resists any change in current, and the more rapid and higher in magnitude that change, the more the solenoid resists it. Exceedingly high voltages may be needed in an attempt to drive such instantaneous currents, as may be appreciated by the fact that standard ignition coils generate their sparkplug voltages in exactly this way.

Applicants have recognized an entirely new way to apply controls to a moving solenoid, using prior knowledge of the many ways the solenoid system may behave in terms of its instantaneous velocity or kinetic energy, its instantaneous location or potential energy with respect to its spring system, and the magnetic flux linkage acting as a general force adding or subtracting energy to the solenoid over time. Applicants make no attempts at all to instantaneously change the state of the solenoid, as in the prior art, but rather they use a proactive change in magnetic flux linkage over a period of predicted time, to steer the solenoid toward and gradually onto a trajectory that will end in a successful landing and latching.

Since the dawn of the invention of internal combustion engines, mechanical mechanisms have been used to move the valves open and closed, and until recently these mechanisms have created a fixed relationship between the crankshaft position and the valve position. It has long been realized that this is not an optimal situation, and special camshafts for racing and for high-torque applications such as farm tractors have been commonplace. Recently, variable valve timing mechanisms have become common, where the entire camshaft itself is moved with regard to the crankshaft, or where linkages between the camshaft and the valve are re-structured to change the valve motion. None of these are yet the optimal solution.

Independent control of each valve, as may be effected with solenoid actuation, is a much larger step in the right direction. With it, substantial gains can be made in fuel economy and exhaust emissions. This is a critical issue today.

2. The failure of the prior art to arrive at the results Applicants obtain shows clearly that Applicants' solution was not obvious at the time of invention.

Although many in the prior art, and including some of the references cited, have labored hard and long to reach the goal of smooth, quiet landing with latching control, none have reached the goal. Applicants have done so, as is evidenced by Exhibit 1 showing the actual performance of a valve/solenoid system under Applicants' control. The mathematics and physics underlying a solenoid system are non-trivial, as attested in the all the prior art and current research papers.

3. The fact that companies such as Ford (Haghgooie '728) and Siemens (Wright '847), who have major global stakes in the field of internal combustion engines, are dedicating resources to the resolution of this problem indicates clearly that even small improvements in this crowded art are significant. Applicants' solution is not small.

As mentioned above, this problem is important. Major worldwide companies, from manufacturers of engines such as Ford and others to manufacturers of engine management systems such as Siemens are spending appreciable time and money on the problem. The patents and papers teaching of progress in this field attest that small improvements are appreciated, that larger improvements are desired, and that Applicants' solution will be welcomed.

4. Using sensorless control in the Applicants' manner reduces the complexity and increases the robustness of prior art systems such as Haghgooie '728 which teach the use of external sensor means such as a linear variable differential transformer (LVDT), which not only introduce their own nuances to measured signals, but also have their own vulnerabilities in an under-the-hood application.

Over the more than 110 years that poppet valves have been the standard for controlling intake and exhaust gases, and as reliable as they have become, they still are subject to wear and premature failures. In effecting a replacement for the current designs, nothing must cause a worsening of reliability or unavoidable increases in cost. Applicants have been working on sensorless control of magnetic actuators for just this reason, and they make every effort to not add levels of complexity or unnecessary mechanisms or sensors that might introduce their own costs or frustrations.

5. Nothing in the prior art suggests or has ever suggested that said prior art be modified, as it must be, to meet Claim 15 or new Claim 52.

Both the control methods and the mathematics which are used in the prior art, and which work hand-in-hand, are drawn from classical approaches. Both these would require restructuring, independently and together, in order to implement Applicants invention.

6. The prior art references are inoperative to the degree that they are incapable of producing the Applicants' beneficial results. Furthermore, while they each may constitute an improvement over their own prior art (which point is arguable), the mathematics and physics underlying their approach does not entirely support the results that would obtain.

As mentioned above, Haghgooie '728 teaches a control method which is immediately and highly sensitive to any discrepancy between where the solenoid is and where it is expected to be. As pointed out clearly by others as well, a solenoid has two broadly different (and overlapping) regions of operation: the far-away region, where (in Katherine Peterson's words) "control authority" is weak,

and close-in where the magnetic field is so non-linear and steeply sloped that control is almost out of control.

Ito '248 teaches a method of controlling a vehicle shifting apparatus using a switching and latching relay network to uncontrollably (in the current sense) turn on and off solenoid actuators. Nothing in the teachings or apparatus of Ito '248 could operate as solenoid control in the context of Applicants' invention.

7. The fact that those skilled in the art, and obviously working on the problem at hand, have not implemented the invention, despite its great advantages, indicates that it is not obvious.

As mentioned earlier, independent control of each valve is a critical issue in the field of fuel economy and exhaust emissions. That no one has implemented Applicants' invention speaks to its unobviousness.

8. Ito '248 does not teach what the Office Action relies upon it as supposedly teaching.

Ito '248 teaches a system, indeed using solenoids but not controlling solenoids' actual paths of motion, for the control of a vehicle transmission to prevent accidental engagement. The control system taught by Ito '248 has no bearing on the control of solenoid motion as considered by Haghgooie '728 or Applicants.

9. The Office Action has made a strained interpretation of the references that could be made only with hindsight.

Nothing in either Haghgooie '728 or Ito '248 talks of state-space control. Applicants have clearly supported in the Specification what is meant by the terminology of Claim 15, which is entirely different from many of such similar terms as used by Haghgooie '728 and by Ito '728. Nowhere is there the inference that Haghgooie '728 discloses means for obtaining parameters indicating the position in state space of a controlled solenoid, nor a path memory means indicative of paths in a state space. Nowhere in Ito '248 is there the suggestion of drive control means setting an output signal in accordance with path memory means, nor indeed of any path memory means at all. Such is simply not germane to the solution of Ito '248.

10. Applicants teach a new principle of operation; they have not followed the lead of the prior art.

Nowhere in the prior art is the suggestion that state-space control be used in the control of a solenoid, nor the expectation that such could be implemented, nor the prediction that if it could, the results would be the solution to this long-standing puzzle. Applicants alone have recognized this approach.

11. Applicants solve a wholly different problem from Ito '248, which fact is made clear in the Claims.

As mentioned above, Ito '248 confronts the problem of a vehicular transmission inadvertently being shifted in to motion or particularly from forward to reverse motion while underway. Ito '248 uses an electrical control circuit to sense the current operating condition of the vehicle and therewith to use the control circuit to prevent inadvertent on/off switching of the solenoids which actuate the transmission. Other than "fully off" and "fully on," Ito '248 makes no attempt to control the solenoid.

Applicant (and Haghgooie '728) face the entirely different, and more subtle, problem of controlling the details of motion of the solenoid along its path from "fully-off" to "fully-on," such that it lands softly and latches in position at each end of its stroke.

12. The Office Action presents no convincing line of reasoning as to why the claimed subject matter, as a whole and including differences over the prior art, would have been obvious.

In the Office Action are numerous statements regarding the obviousness of Claim 15. Few, however, present a clear argument in support of themselves, and none show how Claim 15 would have been obvious.

13. The prior art contains no suggestion that the references be combined in the manner stated or to reach the same results.

Haghgooie '728 makes no suggestion that the control apparatus of Ito '248 for vehicular transmissions could ever in any way be combined with the invention of Haghgooie '728, in any manner; Ito '248 makes no suggestion that the control system of Haghgooie '728 could ever in any way be combined with the invention of Ito '248 in any manner. Neither suggests that any benefit would accrue therefrom.

14. The references are individually complete in themselves. There would be no reason to change their teachings or to add new material.

Haghgooie '728 teaches a method for controlling the position of a solenoid, and claims that said method is successful. Nowhere does Haghgooie '728 suggest a reason for incorporating a shift control apparatus or method to improve the use of induction in determining said position.

Ito '248 teaches a shift control method and apparatus for operating an vehicular transmission. There is no hint in Ito '248 that such apparatus or such method would benefit in any way by the Haghgooie '728 method of measuring the position of a solenoid. Indeed, Ito '248 nowhere makes mention of the position of any solenoid, nor of the relevance of any solenoid's position.

15. Ito '248 is from an entirely different field than that of the invention, and thus is nonanalogous art.

Ito '248 deals with the field of vehicular control and safety. Applicants in no way consider the control or safety of a vehicle, but deal instead with the control of a solenoid or engine valve such that it lands smoothly and latches in position.

16. Even if combined as suggested in the Office Action, the references would not meet the Claim.

As stated above, Ito '248 teaches an apparatus and method using solenoids but not controlling solenoids' paths of motion. Haghgooie '728 teaches a method of using inductance to determine the position of a solenoid. Neither speaks of state-space control, of paths in a state space nor of a path memory means. When combined is any manner, such combination would never provide a path memory means, paths in state space or control by using such state space.

17. The results achieved by the invention are greater than would be expected from the respective results of the references, individually or in combination.

Applicants' results, as manifest in Exhibit 1 as well as in the Specification, are clearly superior to those of Haghgooie '728 in effecting a low-impact landing with latching. As ito '248 teaches uncontrolled solenoid motion, both Applicants and Haghgooie '728 are manifestly superior to the results in Ito '248.

18. The combination of Haghgooie '728 and Ito '248 would require a series of separate, awkward combinative steps that are too involved to be considered obvious.

Ito '248 uses a single wire connecting to a solenoid, the return path being through electrical ground. This permits solenoid 5 and 7 to be, in Ito's words, "energized" or "deenergized" by either passing electrical current through control relays 6 or 8, or not. No additional wires, components or circuitry are needed.

To combine Ito '248 with Haghgooie '728 would require, first, an isolated return circuit for individually measuring the electrical current passing through solenoids 5 and 7 separately. In addition would be required a controlled current source and voltage sense leads, and a digital signal processor. Furthermore, it would require Haghgooie's LVDT position sensor. The net result would be a much more expensive and failure-prone device which could only reduce the solenoids' effectiveness by slowing them down from their normal fully-energized speed which is in any case preferred for actuating a transmission.

Further regarding Claim 15, now rewritten as new Claim 52, Haghgooie '728 does not teach a memory means for storing and retrieving predetermined trajectory information, nor does it teach information describing a multiplicity of trajectories within a state space, such trajectories corresponding to a multiplicity of operating systems. Haghgooie '728 does not teach a means for electively determining the present state of a solenoid, but rather uses an iterative, continuous series of measurements. Haghgooie '728 does not teach means for comparing the present state with predetermined trajectory information, nor a drive control means for setting an output signal in accordance with a distance in state space whereby the dynamically changing state of a solenoid actuator is caused to approach a trajectory among a multiplicity of trajectories.

Ito '248 teaches at column 1, lines 27-29, a signal from a vehicular speed sensor which is supplied to a control unit that energizes two relays. It nowhere teaches or envisions drive control means for setting an output signal in accordance with a distance in state space, or with an error detection means or by comparison to a memory means.

The Rejection of Claim 16 under 35 USC §103(a) is overcome

Claim 16, re-written as new Claim 53, is dependent upon new and allowable Claim 52. Wright '847 at column 11, line 63-67 teaches the control loop logic for defining a single time-dependent path using inductance and rate of change of inductance directly as state variables. It does not teach or suggest a mathematical simulation in any way. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 17 under 35 USC §103(a) is overcome

Claim 17, re-written as new Claim 54, is dependent upon new and allowable Claim 52. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 18 under 35 USC §103(a) is overcome

Claim 18, re-written as new Claim 55, is dependent upon new and allowable Claim 52. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 19 under 35 USC §103(a) is overcome

Claim 19, re-written as new Claim 56, is dependent upon new and allowable Claim 55. Wright '847 teaches (see column 7, line 25) a flux (Figure 5, element 66) and not a flux linkage. As is clear in Applicants' specification, using flux linkage rather than flux itself produces an advantage. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 20 under 35 USC §103(a) is overcome

Claim 20, re-written as new Claim 57, is dependent upon new and allowable Claim 55. Wright '847 teaches at column 6, lines 1-17 an equation for voltage, such equation not involved with position at different times, nor with a measure of velocity, nor with a cumulative total of inductive voltages as asserted in the rejection of Claim 20. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 21 under 35 USC §103(a) is overcome

Claim 21, re-written as new Claim 58, is dependent upon new and allowable Claim 57. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 22 under 35 USC §103(a) is overcome

Claim 22, re-written as new Claim 59, is dependent upon new and allowable Claim 57. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 23 under 35 USC §103(a) is overcome

Claim 23, re-written as new Claim 60, is dependent upon new and allowable Claim 59. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 24 under 35 USC §103(a) is overcome

Claim 24, re-written as new Claim 61, is dependent upon new and allowable Claim 59. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 25 under 35 USC §103(a) is overcome

Claim 25, re-written as new Claim 62, is dependent upon new and allowable Claim 59. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 26 under 35 USC §103(a) is overcome

Claim 26, re-written as new Claim 63, is dependent upon new and allowable Claim 52. Applicants respectfully request reconsideration of this rejection.

The Rejection of Claim 27 under 35 USC §103(a) is overcome

Claim 27, re-written as new Claim 64, is dependent upon new and allowable Claim 52. Applicants respectfully request reconsideration of this rejection.

Conclusion

For the reasons given above, Applicant submits that Claims 1-27, re-written as new Claims 38-64, are now in definite and proper form, that they all define patentably over the prior art, and that this application is now fully in condition for allowance.